

CO₂ Budget and Rectification Airborne Study Final Technical Report

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Introduction.

The main purpose of this award was to supply a platform for the airborne measurements of gases associated with the CO₂ Budget and Regional Airborne Study (COBRA). The original program was to consist of three field programs: the first was to be in 1999, the second in 2000, and the third in 2001. At the end of the second field program, it was agreed that the science could better be served by making the measurements in northern Brazil, rather than in North America. The final North American program would be postponed until after two field programs in Brazil.

A substantial amount of effort was diverted into making plans and preparations for the Brazil field programs. The Brazil field programs were originally scheduled to take place in the Fall of 2002 and Spring of 2003. Carrying out the field program in Brazil was going to be logistically much more involved than a program in the US. Shipping of equipment, customs, and site preparations required work to begin many months prior to the actual measurement program. Permission to fly in that country was also not trivial and indeed proved to be a major obstacle. When we were not able to get permission to fly in Brazil for the 2002 portion of the experiment, the program was pushed back to 2003. When permission by the Brazilian government was not given in time for a Spring of 2003 field program, the experiment was postponed again to begin in the Fall of 2003. When it

appeared that the required permission to fly was not going to be given in time to carry out the program in the Fall of 2003, it was decided to go back to a North American measurement program. This was carried out finally during the summer of 2003. While the actual field work on this last program fell outside the time interval for this award, much of the preparation for this work was done under this award and it does represent the third field program that was originally planned. Therefore, this work is being reported upon in this report.

While the Brazilian experiment did not take place, there was substantial effort that went into the planning of that experiment. Our pilot, Paul LeHardy, traveled to Brazil for a planning meeting during the year to discuss the flight profiles and requirements for the airports to be used. A number of possible combinations of airports and flight plans were discussed at that time. Coordination for the field work in Brazil also was done via telephone and email. Arrangements were made to ship equipment and a customs broker was contacted to assist in the movement of equipment in and out of Brazil.

The 1999 COBRA Field Program.

The first field measurement program was conducted during June of 1999. A summary of the missions flown is given in Table 1. One of the main objectives of the first field program was to test the measurement systems and the means by which the program was to be carried out. This "shakedown" trial resulted in a relatively long time to get all the

instrumentation on the Citation prior to the first field program but was much faster during the subsequent programs. The systems worked reasonably well for the first effort and only a few problems were encountered.

Table 1. Mission summaries for the 1999 COBRA Field Program

Date	Mission Description	Area
990603	Test flight after system integration	GFK-GFK
990605	WELF Tower, Vertical profiles	GFK-Wisc-GFK
990608	WELF Tower	GFK-Wisc-DLH
990608	WELF Tower	DLH-Wisc-GFK
990610	LaGrangian Experiment, soundings	GFK-GFK
990610	LaGrangian Experiment, soundings	GFK-GFK

One problem that was discovered was in the wind measurements. For some of the cross-sections, there was a “saw-tooth” pattern flown. The aircraft was constantly in an abnormal attitude and the winds were found to be in error. This turned out to be a software problem and was eventually corrected. Another problem associated with the continuous changes in altitude was in the measurement of humidity by the aircraft’s dew point sensor. The response time of the instrument was inadequate to accurately determine the vertical profile of humidity for the flight profiles that were being flown. There was an additional problem with the humidity instrument during descent if the aircraft fuselage temperature was colder than the dew point temperature. Since the dew-point sensor was fuselage-mounted, the air passing close to the fuselage would lose moisture. Both of these problems resulted in the installation of a faster response instrument prior to the last program.

The 2000 COBRA Field Program.

The second field measurement program was carried out during August of 2000. The system integration went much more smoothly than that prior to the first field program as the instrumentation configuration was much the same. A summary of the missions flown is given in Table 2.

Table 2. COBRA Flights of 2000 field program

Date-Time	Description	Departure-Destination
00_07_28_20_26_39	Test Flight	Grand Forks
00_08_01_11_54_54	Transects	GFK-Canada-GFK
00_08_01_19_46_02	Transects	GFK-Canada-GFK
00_08_02_12_54_24	Transects and soundings	GFK-ND-GFK
00_08_02_19_45_23	Transects and soundings	GFK-ND-GFK
00_08_04_15_33_58	Transects and soundings	GFK-DEN
00_08_06_14_29_21	Transects and soundings	DEN-PIH
00_08_06_18_57_55	Transects and soundings	PIH-DEN
00_08_08_14_31_48	Transects and soundings	DEN-ICT
00_08_09_13_30_31	Transects and soundings	ICT-EVV
00_08_09_16_29_33	Transects and soundings	EVV-JST
00_08_09_18_54_40	Transects and soundings	JST-BED
00_08_11_12_05_59	Transects and soundings	BED-BGR
00_08_11_18_09_22	Transects and soundings	BGR-BGR
00_08_11_21_35_52	Transects	BGR-BED
00_08_18_11_52_31	Transects and soundings	BED-BGR
00_08_18_18_19_07	Transects and soundings	BGR-BED
00_08_19_12_16_32	Transects and soundings	BED-FNT
00_08_19_15_27_48	Transects and soundings	FNT-GRB
00_08_19_17_57_33	Transects and soundings	GRB-GFK
00_08_23_12_30_55	WELF Tower flight	GFK-DLH
00_08_23_17_27_34	WELF Tower flight	DLH-DLH
00_08_23_20_56_02	WELF Tower flight	DLH-GFK
00_08_24_12_24_51	WELF Tower flight	GFK-DLH
00_08_24_17_33_36	WELF Tower flight	DLH-DLH
00_08_24_20_58_40	WELF Tower flight	DLH-GFK
00_09_15_18_34_31	Test Flight	GFK-GFK
01_01_27_16_32_35	Test Flight	GFK-GFK

As is obvious from the table, there were many more missions flown during 2000 than there were in 1999 and the flights took place across the US, with some flights going into

Canada. The program started out with a LaGrangian experiment in the area around North Dakota. After these flights, a number of large-scale transects were flown, going to Denver, out to Pocatello and back to Denver, and then out to the east coast. While based out of Hanscom Field, in Massachusetts, a number of regional flights were flown in Maine. At the end of those flights, another transect was flown back to Grand Forks. The large-scale transects typically consisted of relatively high altitude (i.e., 20,000-30,000 ft) legs with occasional descents down to about 50 ft over intermediate airports.

There were a couple of mechanical problems during the month. One problem was a generator failure that necessitated staying overnight in Wichita, KS. Another problem with the navigation lights on the airplane caused a delay in one scheduled launch while the aircraft was based at Hanscom Field.

The 2003 COBRA Field Program.

The instrumentation integration for the 2003 field program took place in Colorado at the NCAR Research Aviation Facility (RAF) at Jeffco. This was different from the first two field programs in that the integration in those programs was carried out in Grand Forks. This integration took longer than the one for the 2000 field program due to the fact that the instrumentation configuration was somewhat different. Provisions had been made to allow for a required Brazilian observer on board each of the flights when the plans were to conduct the program in Brazil. When this proved to be unnecessary, the savings in weight and space were taken advantage of by adding a gas chromatograph to the instrumentation configuration. A condensation nucleus counter was also added. This was

deemed to be desirable especially for the Brazil program in that there was a possibility that there might be burning in portions of the selected measurement areas. While this might be apparent in the CO₂ measurements, it would be advantageous to have an independent means of detecting possible smoke effects. While the significance of the effect would not likely be as large in the North American program, it was still felt to be worthwhile. In order to better measure the humidity profiles, a tunable diode laser (TDL) hygrometer was also carried. This instrument was installed prior to this field program and used on another project so that some of the problems with this instrument had been identified and fixed prior to the summer of 2003 field program. Another area that proved difficult in the analysis of data from the previous programs was in the determination of height above ground. This was especially true during flights in the boundary layer. Therefore, the aircraft's radar altimeter was tied into the data system and recorded with the other variables.

One significant problem that was encountered during the integration process was due to the fact that the instrumentation had been mounted on a palette to go into the aircraft easily. Unfortunately, it conflicted with the inertial platform used by the aircraft as part of its wind measurement system. As there was no good solution to this conflict, the inertial platform had to be moved. As the wind system is very sensitive to the angles (pitch, roll, and yaw), a substantial amount of recalibration had to be done. Some of this work could be done during the field program, but much of it had to be finished after the conclusion of the program. This necessitated a substantial amount of effort in recalibrating the wind system. However, we feel confident that the winds are now as accurate as before.

An overview of the flight history is shown in Figures 1 and 2. The Citation Flew out of Boulder to Oregon and out over the Pacific before going up the west coast into Canada. The aircraft then flew across Canada and back into the US on the east coast. While there, it flew a number of regional missions before flying back to Boulder. Upon arrival at Boulder, the aircraft flew a regional experiment out into the Gulf and another one over the CART site in Oklahoma. The aircraft then flew the same route with (fewer regional experiments) out to the west coast, up through Canada, down the east coast and back to Boulder.

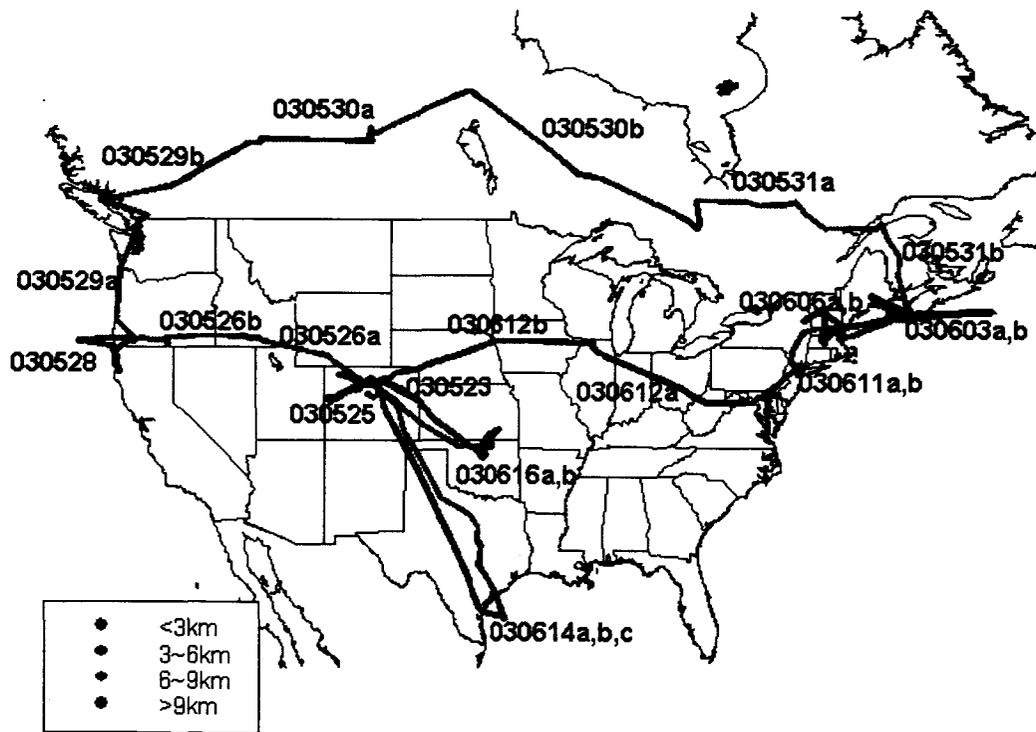


Figure 1. History of the Citation flights during Summer 2003 COBRA Field Program (from the COBRA Web Site) for the period 5/25/03 through 6/16/03.

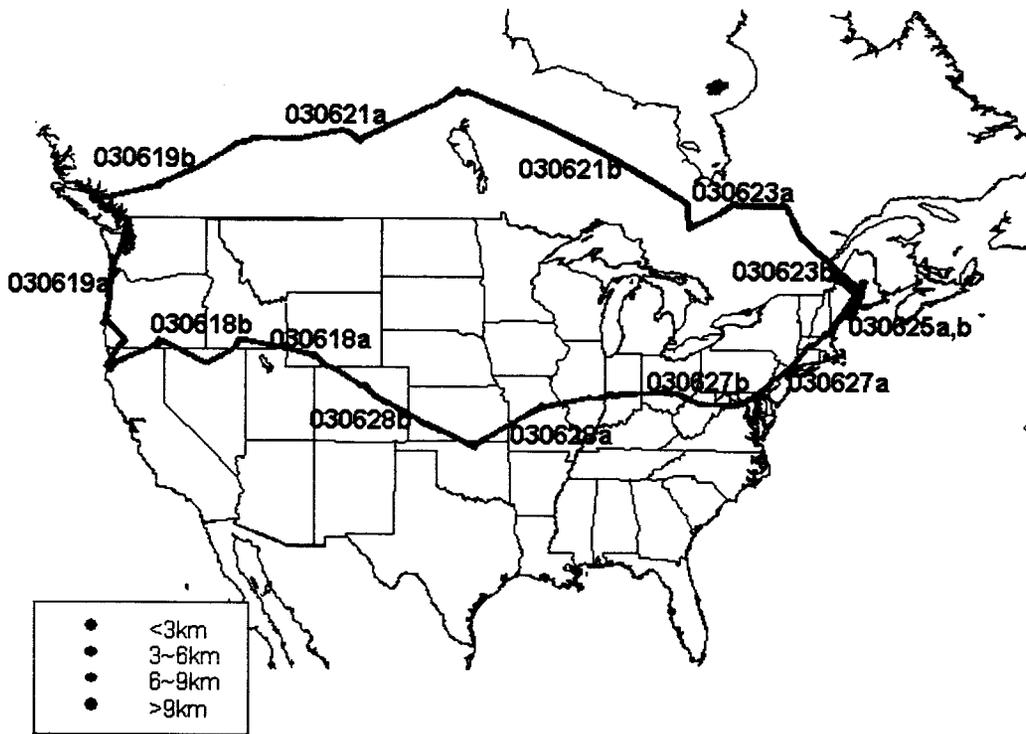


Figure 2. History of the Citation flights during Summer 2003 COBRA Field Program (from the COBRA Web Site) for the period 6/18/03 through 6/28/03.

A summary of the flights during 2003 is given in Table 3.

Table 3. COBRA Flights for 2003

Date	Designation	Flight Description	From/to
23 May 2003	030523	First test flight	Jeffco-Jeffco
25 May 2003	030525	Second test flight	Jeffco-Jeffco
26 May 2003	030526a 030526b	Transit	BJC(RKS)TWF (LKV) MFR
28 May 2003	030528	Offshore flight	MFR-MFR
29 May 2003	030529a 030529b	Transit to CYEG via CmbI Rr	MFR-CYEG
30 May 2003	030530a 030530b	Transit to CYTS	CYEG-CYTS
31 May 2003	030531a 030531b	Transit to Boston	CYTS-Boston
3 June 2003	030603a 030603b	Offshore flight out to Sable Isl	Pease (NH) -Pease
6 June 2003	030606a 030606b	Harvard Forest Regional Exp	Pease (NH) - Pease
11 June 2003	030611a 030611b	1st day of Transit	Pease (NH) - MD
12 June 2003	030612a 030612b	2nd day of Transit	MD - Jeffco
14 June 2003	030614a,b,c	Texas/Gulf Regional Exp	Jeffco-Jeffco
16 June 2003	030616a 030616b	ARM/CART Regional Exp	Jeffco-Jeffco
18 June 2003	030618a 030618b	Transit to Medford,	Jeffco-Medford
19 June 2003	030619a 030619b	Transit	MFR-CYEG
21 June 2003	030621a 030621b	Transit to CYTS	CYEG-CYTS
23 June 2003	030623a 030623b	Transit to Pease	CYTS-Pease
25 June 2003	030625a 030625b	Howland Regional Exp	Pease (NH) - Pease
27 June 2003	030627a 030627b	1st day of Transit	Pease - Terre Haute
28 June 2003	030628a 030628b	2nd day of Transit	Terre Haute - Jeffco

Results.

While the analysis of the data collected was outside the scope of this contract, a considerable amount of effort has gone into examination of the data collected. Much of the analysis of this substantial data set is still going on, but some of the results of these field measurements have been reported upon to date. Some of these reports are listed below.

Published works resulting from the COBRA Field Campaigns.

Gerbig, Lin, Wofsy, Daube, Andrews, Stevens, Bakwin, Grainger, 2003: "Towards constraining regional scale fluxes of CO₂ with atmospheric observations over a continent: 1. Observed Spatial Variability from airborne platforms", *Journal of Geophysical Research, Atmospheres*. Accepted for publication on 9/2/03

Gerbig, Lin, Wofsy, Daube, Andrews, Stevens, Bakwin, Grainger, 2003: "Towards constraining regional scale fluxes of CO₂ with atmospheric observations over a continent: 2. Analysis of COBRA data using a receptor oriented framework", *Journal of Geophysical Research, Atmospheres*. Accepted for publication on 9/2/03

Lin, J.C., C. Gerbig, S.C. Wofsy, A.E. Andrews, B.C. Daube, K.J. Davis, and C.A. Grainger, 2003: "A near-field tool for simulating the upstream influence of atmospheric observations: the Stochastic Time-Inverted Lagrangian Transport (STILT) model", *Journal of Geophysical Research*, 108 (D16), 4493, doi:10.1029/2002JD003161.

Bakwin, P. S.; Tans, P. P.; Stephens, B. B.; Wofsy, S. C.; Gerbig, C.; Grainger, A.. 2003:"Strategies for measurement of atmospheric column means of carbon dioxide from aircraft using discrete sampling", *J. Geophys. Res.* Vol. 108, No. D16, 4514 10.1029/2002JD003306